High Resolution Silicon-on-Insulator Mid-Infrared Spectrometers operating at 3.3 µm

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***Abstract*—The characterization of silicon-on-insulator arrayed waveguide grating wavelength (de)multiplexers operating at 3.3 µm is reported. The filters have a channel spacing between 200 GHz and 50 GHz and feature low insertion loss (2-3dB), low crosstalk level (20 dB) and low waveguide loss (2.6 dB/cm).**

I. Introduction

Silicon-on-Insulator (SOI) waveguide technology is rapidly expanding its operation window towards longer wavelengths for novel compact sensing and instrumentation applications while still leveraging the maturity and scalability of CMOS fabrication technology [1]. The mid-infrared wavelength range at 3.3 µm is of particular interest for spectroscopic detection of hydrocarbons in liquid or gas samples. To realize a compact and cheap spectroscopic system, one could envision an integrated dispersive spectrometer together with on-chip detectors and a broadband source. For high resolution spectroscopy applications, an array of mid-infrared quantum cascade or interband cascade laser sources can be used to probe the mid-infrared absorption spectrum. Each element of the array can be a single wavelength distributed feedback (DFB) laser which can be thermally tuned over a narrow wavelength range. By small alterations in the fabrication process an array of lasers with different emission wavelengths can be fabricated [2]. For practical compact applications it would be beneficial to couple such an array to a single diffraction limited beam using an integrated wavelength multiplexer.

In both cases there is a need for integrated wavelength (de)multiplexers such as arrayed waveguide grating (AWG) structures which can be designed with different free spectral range (FSR) and channel spacings. This paper demonstrates a high resolution AWG design at 3.3 µm with different channel spacings from 200 GHz (7.3 nm) to 50 GHz (1.8 nm) which could be used as a wavelength multiplexer for future mid-infrared laser array spectroscopy systems.

II. Experiments

The filters are fabricated on a 200 mm SOI wafer with a 400 nm thick crystalline Si device layer and 2 µm buried oxide layer thickness. Rib waveguides and grating couplers are defined with a 180 nm deep etch and are cladded with SiO_2 and planarized down to the silicon device layer. The photonic circuit is designed for 3.3 µm and TE polarized light. The AWGs have six channels with four different channel spacings $\{200,140,80,50\}$ GHz. These four filters have the same star coupler design which is defined by the parameters in table I.

TABLE I
AWG design parameters, detailed explanation of quantities can be found in [3]

No. of arrayed waveguides	32
free propagation length (µm)	130
waveguide width (µm)	1.125
expanded WG width (µm)	2.2
taper length (µm)	75
bend radius (µm)	50
aperture width (µm)	3.25
arrayed WG spacing (nm)	250

The filters are characterized by using a continuous wave optical parametric oscillator (OPO) system from Aculight. The light is chopped and coupled to a single mode ZrF_4 fiber which is then vertically coupled to the chip. A lock-in amplifier measures the response of a liquid nitrogen cooled $InSb$ detector at the modulation frequency. The response is normalized to a reference thermopile detector which measures a fraction of the output power of the OPO. In parallel, the source wavelength is continuously monitored with a fraction of the light coupled to a wavemeter. Fine wavelength tuning of the OPO is achieved by coordinated tuning of the position of the nonlinear crystal, intra-cavity etalon angle and piezo-electric strain on the seed laser.

The AWG response is normalized to a reference waveguide and the results are shown in Fig 1. The insertion loss of all four AWGs is between 2 and 3 dB. The crosstalk level, defined here as the highest contribution of unwanted signal within any channel, is around 20 dB for all four designs.

The waveguide loss is estimated by using a set of four spirals with increasing length from 0.65 cm to 5.5 cm. The waveguide loss at 3.32 µm is estimated to be 2.6±0.2 dB/cm. It is worth noting that after a few days of exposure to ambient air, as opposed to controlled cleanroom environment, the waveguide loss increased to 4.5 dB/cm due to organic contamination from air. The loss was decreased back to nominal values by cleaning the chip with acetone and a 15 min O_2 plasma treatment. The performance of the AWGs was unaffected by the increased loss.

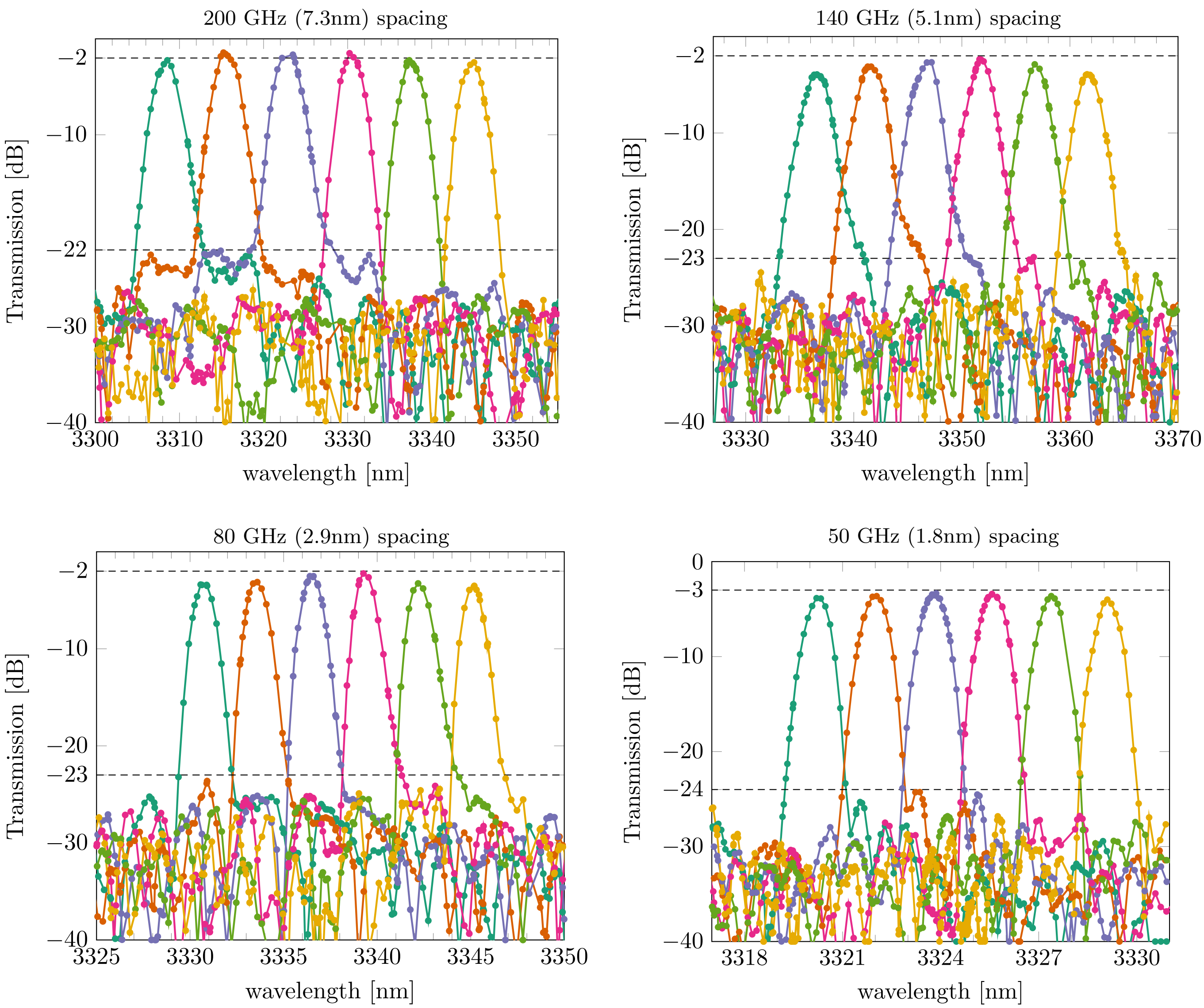

Fig. 1. Transmission normalized to a reference waveguide of four different SOI AWGs operating in the 3.3 μm wavelength range. The insertion loss (2-3 dB) and crosstalk levels (20-21 dB) are indicated by the dashed lines.

Four different optimal combinations of the star coupler aperture width {2.45,3.25,4.50,6.00} μm and free propagation range {80,130,235,395} μm were investigated for the 200 GHz AWG. The performance variations were found to be insignificant: the insertion loss is -2 dB and the crosstalk varies between 20 and 24 dB.

III. Conclusion

AWGs operating at 3.3 μm are demonstrated with low insertion loss, good crosstalk levels and low waveguide loss. The high resolution AWG with 50 GHz spacing can potentially be used as an integrated multiplexer for a future compact laser array spectroscopy system for hydrocarbon analysis.

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